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No. 1374

EXPERIMENTAL STUDIES OF THE KNOCK-LIMITED BLENDING
CHARACTERISTICS OF AVIATION FUELS

II - INVESTIGATION OF LEADED PARAFFINIC FUELS
IN AN AIR-COOLED CYLINDER

By Jerrold D. Wear and Newell D. Sanders

Flight Propulsion Research Laboratory
Cleveland, Ohio



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EXPERIMENTAL STUDIES OF THE KNOCK-LIMITED BLENDING
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SUMMARY

The relation between knock limit and blend composition of selected aviation fuel components individually blended with virgin base and with alkylate was determined in a full-scale air-cooled aircraft-engine cylinder. In addition the following correlations were examined:

(a) The knock-limited performance of a full-scale engine at lean-mixture operation plotted against the knock-limited performance of the engine at rich-mixture operation for a series of fuels

(b) The knock-limited performance of a full-scale engine at rich-mixture operation plotted against the knock-limited performance at rich-mixture operation of a small-scale engine for a series of fuels

In each case the following methods of specifying the knock-limited performance of the engine were investigated:

(1) Knock-limited indicated mean effective pressure

(2) Percentage of S-4 plus 4 ml TEL per gallon in M-4 plus 4 ml TEL per gallon to give an equal knock-limited indicated mean effective pressure

(3) Ratio of indicated mean effective pressure of test fuel to indicated mean effective pressure of clear S-4 reference fuel, all other conditions being the same.

Results indicated that the knock-limited indicated mean effective pressures of the paraffinic fuels investigated, except the neohexane blends at lean mixtures for a spark advance of 20° B.T.C., followed the reciprocal blending equation provided that the temperature of the cylinder walls near the knocking zone was held constant.

Percentage of S-4 reference fuel in M-4 reference fuel (both fuels containing 4 ml TEL/gal) for an equal knock-limited indicated mean effective pressure of the paraffinic fuels tested at a spark advance of 20° B.T.C. gave ratings of the paraffinic fuels that were independent of the type of engine used in these tests and of the fuel-air ratio.

INTRODUCTION

An investigation of the knock-limited blending characteristics of aviation-fuel components is being conducted at the NACA Cleveland laboratory to determine the extent of the applicability of the reciprocal blending relation developed in reference 1. This relation is as follows:

$$\frac{1}{imep} = \frac{N_1}{(imep)_1} + \frac{N_2}{(imep)_2} + \frac{N_3}{(imep)_3} + \dots$$

where

$imep$	knock-limited indicated mean effective pressure of the fuel blend
$(imep)_1, (imep)_2, (imep)_3 \dots$	knock-limited indicated mean effective pressures of components 1, 2, 3, . . . , respectively, when individually tested
$N_1, N_2, N_3 \dots$	mass fractions of components 1, 2, 3, . . . , respectively, in the fuel blend

The results of a preliminary investigation (reference 2) with blends of a 62-octane paraffinic gasoline and an aviation alkylate and blends of S and M reference fuels indicated that the

reciprocal blending relation derived in reference 1 is applicable to blends of paraffinic fuels at rich mixtures. On the other hand, the relation was not applicable to lean-mixture data for paraffinic fuels and is probable that the disagreement may have resulted from improper control of cylinder temperatures adjacent to the knocking zone.

The primary purpose of the investigation reported is to study the blending characteristics of a number of leaded paraffinic aviation-fuel components in a full-scale air-cooled engine cylinder. A secondary purpose is to compare the following correlations:

(a) The knock-limited performance of a full-scale engine at lean-mixture operation plotted against the knock-limited performance of the engine at rich-mixture operation for a series of fuels

(b) The knock-limited performance of a full-scale engine at rich-mixture operation plotted against the knock-limited performance at rich-mixture operation of a small-scale engine for a series of fuels

In each case the following methods of specifying the knock-limited performance of the engine were investigated:

(1) Knock-limited indicated mean effective pressure

(2) Percentage of S-4 plus 4 ml TEL per gallon in M-4 plus 4 ml TEL per gallon to give an equal knock-limited indicated mean effective pressure

(3) Ratio of indicated mean effective pressure of test fuel to indicated mean effective pressure of clear S-4 reference fuel, all other conditions being the same

Runs were made on a full-scale air-cooled cylinder; F-4 ratings were determined for most of the blends.

FUELS

The base fuels used in this investigation were alkylate and virgin base. The blending components were:

Triptane (2,2,3-trimethylbutane)
Hot-acid octane
Isopentane (2-methylbutane)
Diisopropyl (2,3-dimethylbutane)
Neohexane (2,2-dimethylbutane)

The base fuels and all blending components contained 4 ml TEL per gallon.

Triptane, hot-acid octane, isopentane, diisopropyl, and neohexane were individually blended with a virgin base stock and tested at spark advances of 20° and 30° B.T.C. Triptane and hot-acid octane were blended with alkylate and tested at a spark advance of 20° B.T.C.

The following reference fuels were also investigated at these engine conditions to obtain the reference-fuel framework:

S-4
S-4 plus 4 ml TEL per gallon
50-percent S-4 and 50-percent M-4 both
leaded to 4 ml TEL per gallon

The triptane was supplied by the General Motors Corporation.

APPARATUS AND PROCEDURE

An investigation was conducted with an R-2800 cylinder mounted on a CUE crankcase. The apparatus was the same as described in detail in reference 2, with the addition of a thermocouple embedded in the cylinder head about one-sixteenth inch from the combustion-chamber wall at the exhaust end zone (fig. 1). The knocking zone was assumed to coincide with the exhaust end zone. An automatic temperature regulator was attached to this thermocouple and controlled the cooling-air flow to maintain the temperature constant at the thermocouple.

The engine was operated at the following conditions, which were changed from the conditions in reference 2 to permit a greater percentage of triptane in base fuel to be tested:

Compression ratio	7.7
Spark advance, deg B.T.C.	20 and 30
Engine speed, rpm	2000
Condition of fuel-air mixture	Prevaporized
Inlet-mixture temperature, °F	240
Cooling-air temperature, °F	100 to 110
Cylinder-head temperature at exhaust end zone, °F	350

The temperature of the rear spark-plug bushing varied from 375° to 425° F.

The test procedure was the same as the procedure described in reference 2.

RESULTS AND DISCUSSION

Mixture-response curves. - The mixture-response curves for the reference fuels (S-4 and 50-percent S-4 plus 50-percent M-4), base fuels, and blends of base fuels and blending agents are shown in figure 2. The blends of base fuels and blending agents shown contain the maximum concentration of blending agents tested in this investigation. Complete mixture-response curves were not obtained for blends of lower concentration.

The knock-limited performance of various blends of base fuels with blending components at fuel-air ratios of 0.067 and 0.10 is summarized in table I. The performance values are given in terms of knock-limited indicated mean effective pressure for two spark settings.

The variation of knock-limited indicated mean effective pressure with blend composition of blends of S-4 plus 4 ml TEL per gallon with M-4 plus 4 ml TEL per gallon are given in figure 3. Interpolated mixture-response curves of blends of the same reference fuels for intervals of 5-percent concentration of S-4 are shown in figure 4. The ordinate is a reciprocal scale and, because the data in figure 3 fall on straight lines, the curves are equally spaced. A curve of clear S-4 is also shown on this figure.

Relation of knock limit to blend composition. - The variation of knock-limited indicated mean effective pressure with blend composition of several fuels is shown in figures 5 to 11.

The ordinates are reciprocal scales of knock-limited indicated mean effective pressure and the abscissas are linear scales of blend composition expressed as percentage by weight. Data are plotted from figure 2 and table I. With the exception of neohexane at lean mixtures for a spark advance of 20° B.T.C. (fig. 11(a)), the data can be represented by straight lines.

Triptane. - Triptane is of special interest because it gives the highest knock-limited performance of all the paraffinic fuels tested. The knock-limited-mixture-response curves for pure triptane plus 4 ml TEL per gallon at both spark settings are extrapolated from data for blends with virgin base (fig. 2) as shown in figure 12. The curves are equally spaced on a reciprocal ordinate scale because the data in figure 5 fall on straight lines. The performance of triptane is greatly depreciated by advancing the spark.

Correlation of knock ratings. - The assigned ratings for the fuels studied at spark advances of 20° and 30° B.T.C. and also the F-4 ratings are presented in table II. Ratings above 100 (expressed in terms of percentage S-4 with M-4) were estimated by means of the straight-line extrapolations in figure 3. Similar extrapolations were used to obtain F-4 ratings above 100.

The correlations of indicated mean effective pressure rich against indicated mean effective pressure lean (knock-limited imep obtained from the full-scale air-cooled cylinder at fuel-air ratios of 0.10 and 0.067, respectively) (fig. 13(a)) and of indicated mean effective pressure at F-4 conditions (knock-limited imep obtained from an F-4 engine at a fuel-air ratio of 0.11) against indicated mean effective pressure rich (fig. 14(a)) are good for a spark advance of 20° B.T.C. The data points for the various paraffins scatter, however, on either side of the correlation line at a spark advance of 30° B.T.C. for indicated mean effective pressure rich against indicated mean effective pressure lean (fig. 13(b)). This line is established by the two reference fuels, S-4 plus 4 ml TEL per gallon and the mixture of 50-percent S-4 and 50-percent M-4 both leaded to 4 ml TEL per gallon. This result indicates that as the severity of engine conditions was increased, the constancy of engine ratings of one paraffin in terms of two other paraffins did not always hold. The indicated mean effective pressure at F-4 conditions against indicated mean effective pressure rich also shows more deviation from the correlation line as engine conditions were increased in severity (fig. 14(b)).

Ratings expressed as percentage S-4 in M-4 (both fuels containing 4 ml TEL/gal) for equal knock-limited indicated mean effective pressure of the paraffinic fuels at a spark advance of 20° B.T.C. show good correlation when full-scale engine lean-mixture performance is plotted against full-scale engine rich-mixture operation (fig. 15). The correlation is also good when full-scale engine rich-mixture operation at 20° B.T.C. is plotted against the F-4 condition (fig. 16).

Ratings expressed as ratios of knock-limited indicated mean effective pressure of test fuel relative to indicated mean effective pressure of clear S-4 at either spark setting are not as constant for rich against lean-mixture operation (fig. 17) as they are for F-4 condition against rich-mixture operation (fig. 18).

SUMMARY OF RESULTS

From an investigation of aviation fuel components individually blended with virgin base and alkylate to determine the relation between knock limit and blend composition and to compare methods of correlating the knock-limited data, the following results were obtained:

1. The knock-limited indicated mean effective pressure of the paraffinic fuels tested (with the exception of neohexane at lean mixtures for a spark advance of 20° B.T.C.) followed the reciprocal blending equation provided that the temperature of the cylinder walls near the knocking zone was held constant.
2. Knock-limited performance expressed in terms of percentage S-4 in M-4 (both fuels contain 4 ml TEL/gal) to give an equal knock-limited indicated mean effective pressure gave ratings of the paraffinic fuels tested that correlated better than ratings expressed by knock-limited indicated mean effective pressure or ratio of indicated mean effective pressure of test fuel to the indicated mean effective pressure of clear S-4 reference fuel. Correlation of ratings specified by ratio of indicated mean effective pressure of test fuel to indicated mean effective pressure of clear S-4 reference fuel was not as good as the other two methods.

3. Percentage of S-4 reference fuel in M-4 reference fuel (both fuels containing 4 ml TEL/gal) for an equal knock-limited indicated mean effective pressure of the paraffinic fuels tested at a spark advance of 20° B.T.C. gave ratings of the paraffinic fuels that were independent of the type of engine used in these runs and of the fuel-air ratio. However, the ratings were not independent of the type of engine and the fuel-air ratio when the spark setting was increased from 20° to 30° B.T.C.

Flight Propulsion Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, June 4, 1947.

REFERENCES

1. Sanders, Newell D.: A Method of Estimating the Knock Rating of Hydrocarbon Fuel Blends. NACA Rep. No. 760, 1943.
2. Sanders, Newell D., Hensley, Reece V., and Breitwieser, Roland: Experimental Studies of the Knock-Limited Blending Characteristics of Aviation Fuels. I - Preliminary Tests in an Air-Cooled Cylinder. NACA ARR No. E4I28, 1944.

TABLE I - KNOCK-LIMITED INDICATED MEAN EFFECTIVE PRESSURE OF BLENDS
OF AVIATION FUEL COMPONENTS WITH BASE FUELS

[Full-scale air-cooled cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F. All fuels contained 4 ml TEL/gal]

Spark advance, 20° B.T.C.				Spark advance, 30° B.T.C.			
Fuel blend (percent by weight)		imep Fuel-air ratio		Fuel blend (percent by weight)		imep Fuel-air ratio	
		0.067	0.10			0.067	0.10
S-4	M-4			S-4	M-4		
61.7	38.3	108	139	62.6	37.4	100	136
72.3	27.7	135	156	75.0	25.0	119	155
82.4	17.6	168	185	84.8	15.2	144	174
90.0	10.0	196	214	92.5	7.5	169	204
95.0	5.0	218	238	-----	-----	-----	-----
Triptane	Virgin base			Triptane	Virgin base		
10.1	89.9	159	182	15.1	84.9	128	175
20.0	80.0	177	200	30.1	69.9	140	201
30.2	69.8	199	216	40.2	59.8	169	225
39.8	60.2	221	241	50.0	50.0	182	256
-----	-----	-----	-----	60.1	39.9	206	-----
Hot-acid octane	Virgin base			Hot-acid octane	Virgin base		
10.0	90.0	155	172	14.9	85.1	124	170
25.5	74.5	171	189	30.0	70.0	134	186
39.9	60.1	185	203	49.8	50.2	150	212
55.2	44.8	207	231	65.0	35.0	172	237
70.0	30.0	224	256	-----	-----	-----	-----
80.3	19.7	246	280	-----	-----	-----	-----
90.2	9.8	261	311	-----	-----	-----	-----
Isopentane	Virgin base			Isopentane	Virgin base		
10.1	89.9	157	167	15.0	85.0	122	166
19.8	80.2	161	175	32.2	67.8	136	173
34.8	65.2	173	182	50.0	50.0	146	-----
42.4	57.6	179	188	-----	-----	-----	-----
Diisopropyl	Virgin base			Diisopropyl	Virgin base		
21.9	78.1	173	186	19.9	80.1	131	174
35.1	64.9	197	214	38.8	61.2	150	199
54.8	45.2	221	245	55.2	44.8	166	222
70.0	30.0	253	279	68.8	31.2	179	246
Neohexane	Virgin base			Neohexane	Virgin base		
13.5	86.5	161	176	20.3	79.7	131	171
30.1	69.9	174	189	38.5	61.5	145	188
45.1	54.9	188	200	53.0	47.0	167	203
64.7	35.3	206	214	60.0	40.0	-----	208
83.8	16.2	225	233	-----	-----	-----	-----
Triptane	Alkylate			NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS			
7.7	92.3	212	241				
15.1	84.9	225	256				
25.1	74.9	244	272				
33.3	66.7	260	297				
40.0	60.0	-----	308				
Hot-acid octane	Alkylate						
10.1	89.9	210	236				
24.9	75.1	224	251				
45.0	55.0	235	265				
64.8	35.2	249	291				
85.0	15.0	264	321				

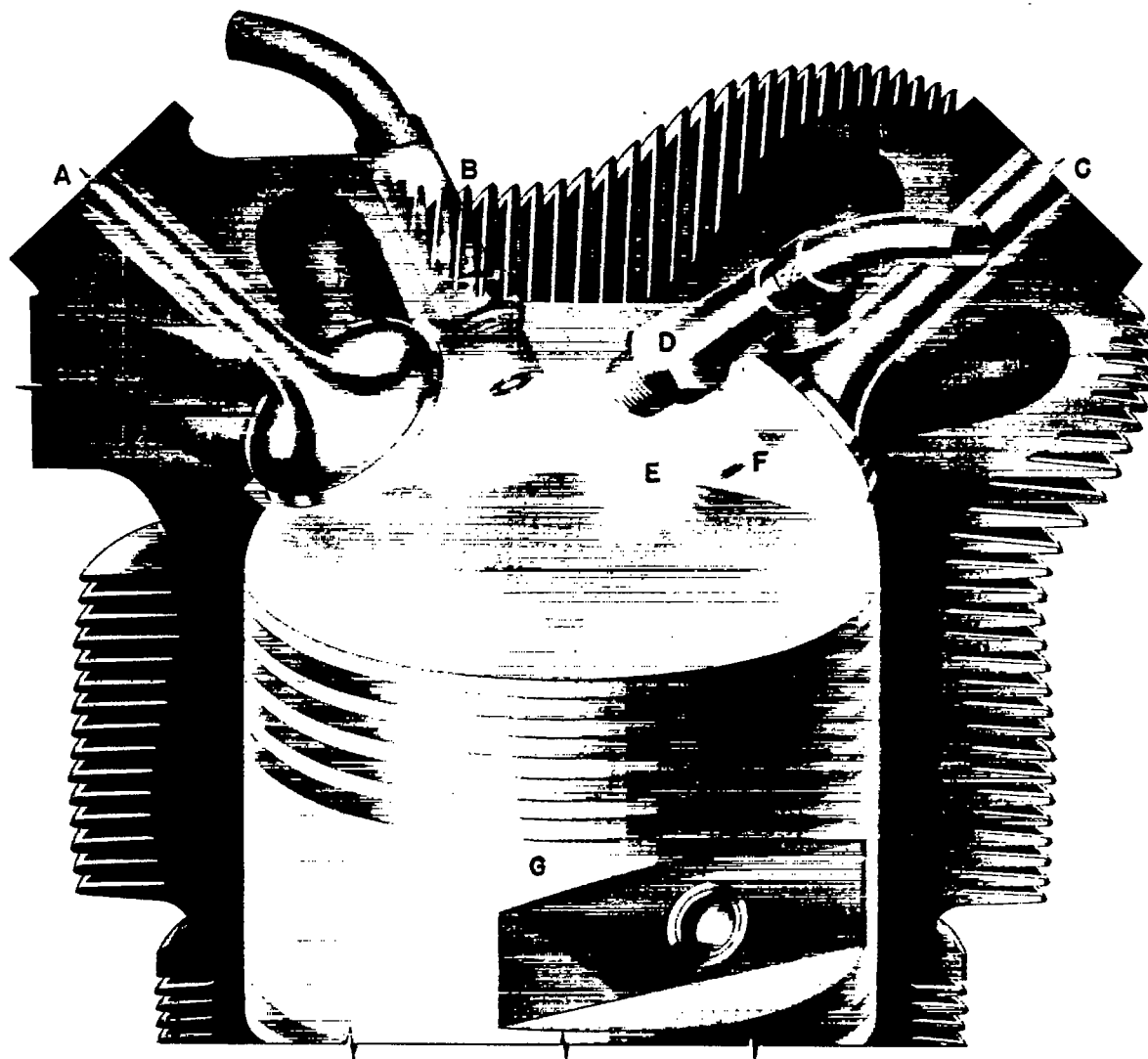
TABLE II - COMPARISON OF KNOCK LIMITS OF 10 FUELS IN FULL-SCALE
AIR-COOLED CYLINDER AND F-4 ENGINE

[For each compound there are three rows of values: the first row is imep, lb/sq in.; the second is percentage S-4 + 4 ml TEL/gal in M-4 + 4 ml TEL/gal; and the third row is the ratio of imep of test fuel to imep of clear S-4. Compression ratio, 7.7; spark advance, 20° and 30° B.T.C.; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F]

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Fuel	Concen- tration of TEL (ml/gal)	F-4 engine (fuel- air ratio, 0.11)	Full-scale air-cooled cylinder			
			Spark advance, 20° B.T.C.		Spark advance, 30° B.T.C.	
			Fuel-air ratio		Fuel-air ratio	
			0.087	0.10	0.067	0.10
Triptane (2,2,3-trimethyl- butane)	4	^a 740	^a 850	^a 700	^a 540	^a 760
		123	125	124	123	131
		4.84	5.55	3.68	5.94	4.63
Diisopropyl (2,3-dimethyl- butane)	4	325	^a 360	^a 365	^a 247	^a 330
		109.5	111.5	112	108	112
		2.12	2.35	2.02	2.71	2.11
Hot-acid octane	4	^a 310	281	345	^a 218	^a 328
		108	105	109	104	112
		2.03	1.84	1.82	2.40	2.14
S-4 reference fuel	4	233	244	268	198	239
		100	100	100	100	100
		1.52	1.60	1.41	2.20	1.56
Neohexane (2,2-dimethyl- butane)	4	^a 243	233	256	^a 270	^a 264
		102	98	98	109	105
		1.59	1.52	1.35	2.86	1.72
Isopentane (2-methylbutane)	4	^a 210	^a 243	^a 240	^a 216	^a 220
		96	99.5	95	103	97
		1.37	1.59	1.26	2.37	1.44
Alkylate	4	196	202	232	-----	-----
		93.5	93.5	93.5	-----	-----
		1.28	1.32	1.22	-----	-----
Virgin base stock	4	139	147	165	114	153
		77.5	76.5	76	72	74
		0.91	0.96	0.87	1.25	1.00
50-percent S-4 + 50-percent M-4	4	^a 93	101	118	87	114
		50	50	50	50	50
		0.61	0.66	0.62	0.955	0.745
S-4 reference fuel	0	153	153	190	91	153
		82.5	79	83.5	53	74
		1.00	1.00	1.00	1.00	1.00

^aExtrapolated from data for blends.



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- | | |
|--------------------|----------------------------|
| A Intake valve | F Thermocouple to measure |
| B Rear spark plug | temperature of combustion- |
| C Exhaust valve | chamber wall at exhaust |
| D Front spark plug | end zone |
| E Exhaust end zone | G Piston |

Figure 1. - Approximate location of exhaust end zone.

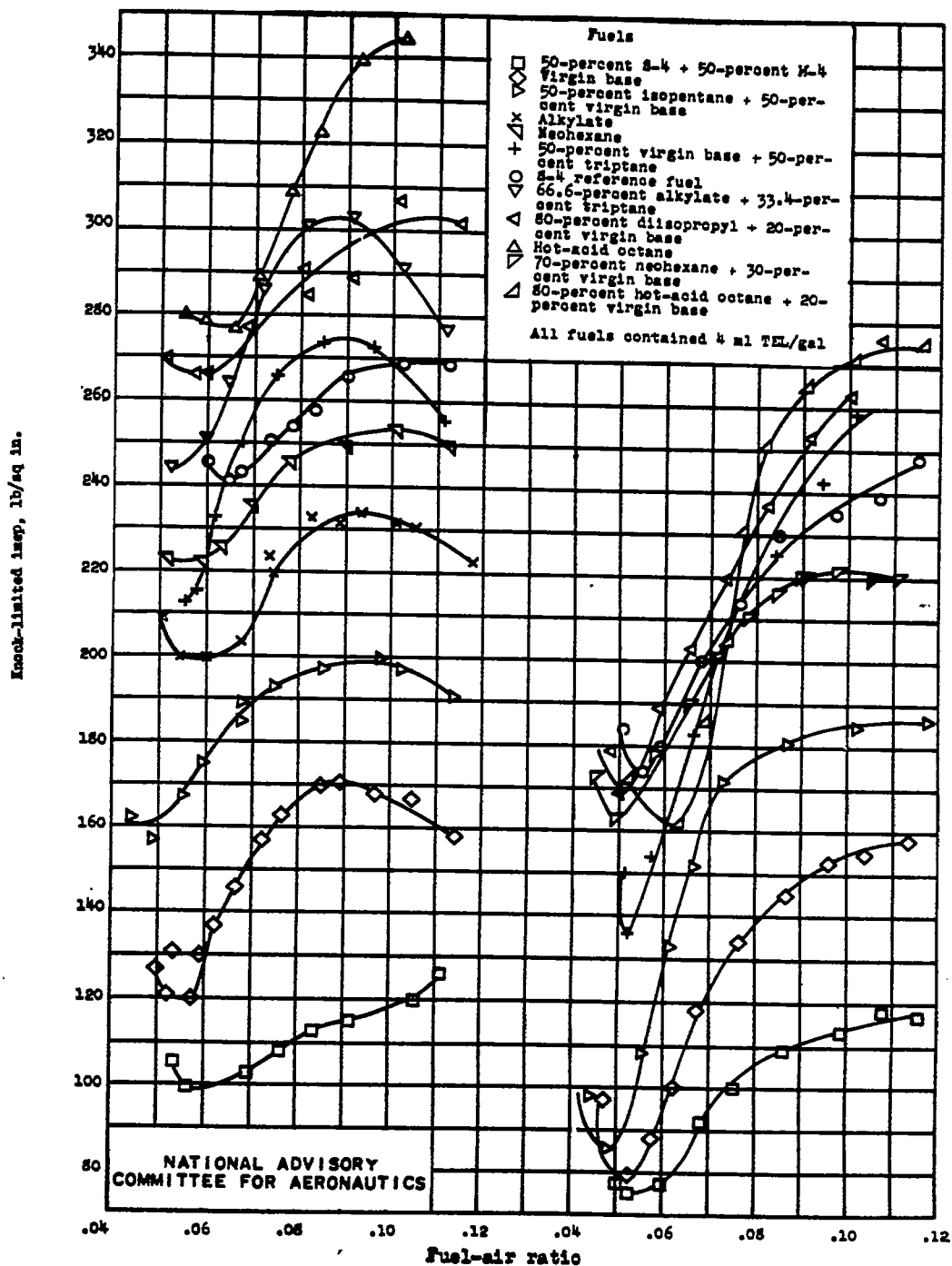


Figure 2. - Knock-limited performance of aviation-fuel components, base fuels, reference fuels, and blends of aviation-fuel components and base fuels. Full-scale air-cooled cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.

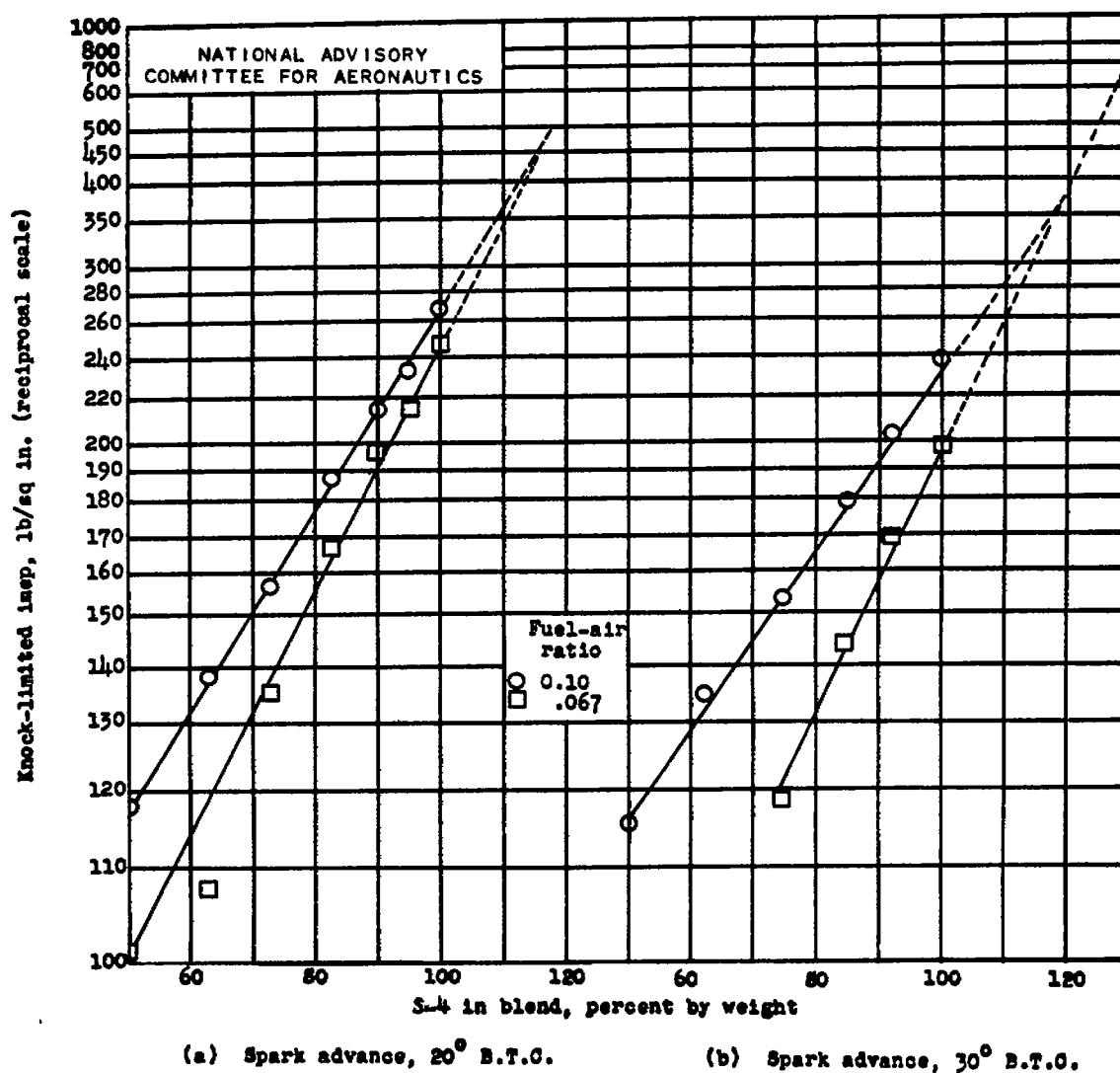


Figure 3. - Relation of knock limit to composition of blends of S-4 with M-4. All fuels contain 4 ml TEL per gallon. Full-scale air-cooled cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.

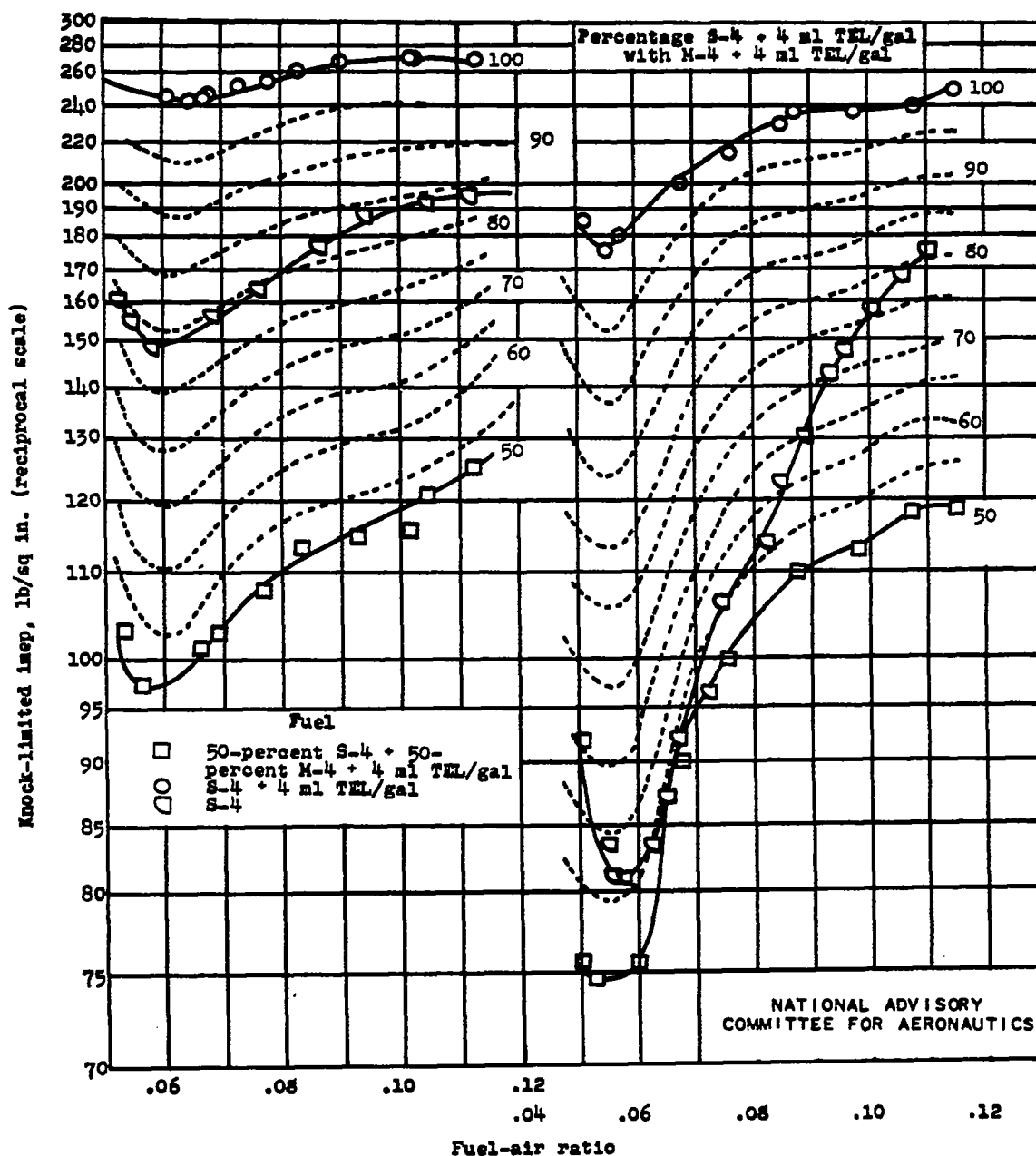


Figure 4. - Blending characteristics of S-4 and M-4 reference fuels plus 4 ml TEL per gallon. Full-scale air-cooled cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.

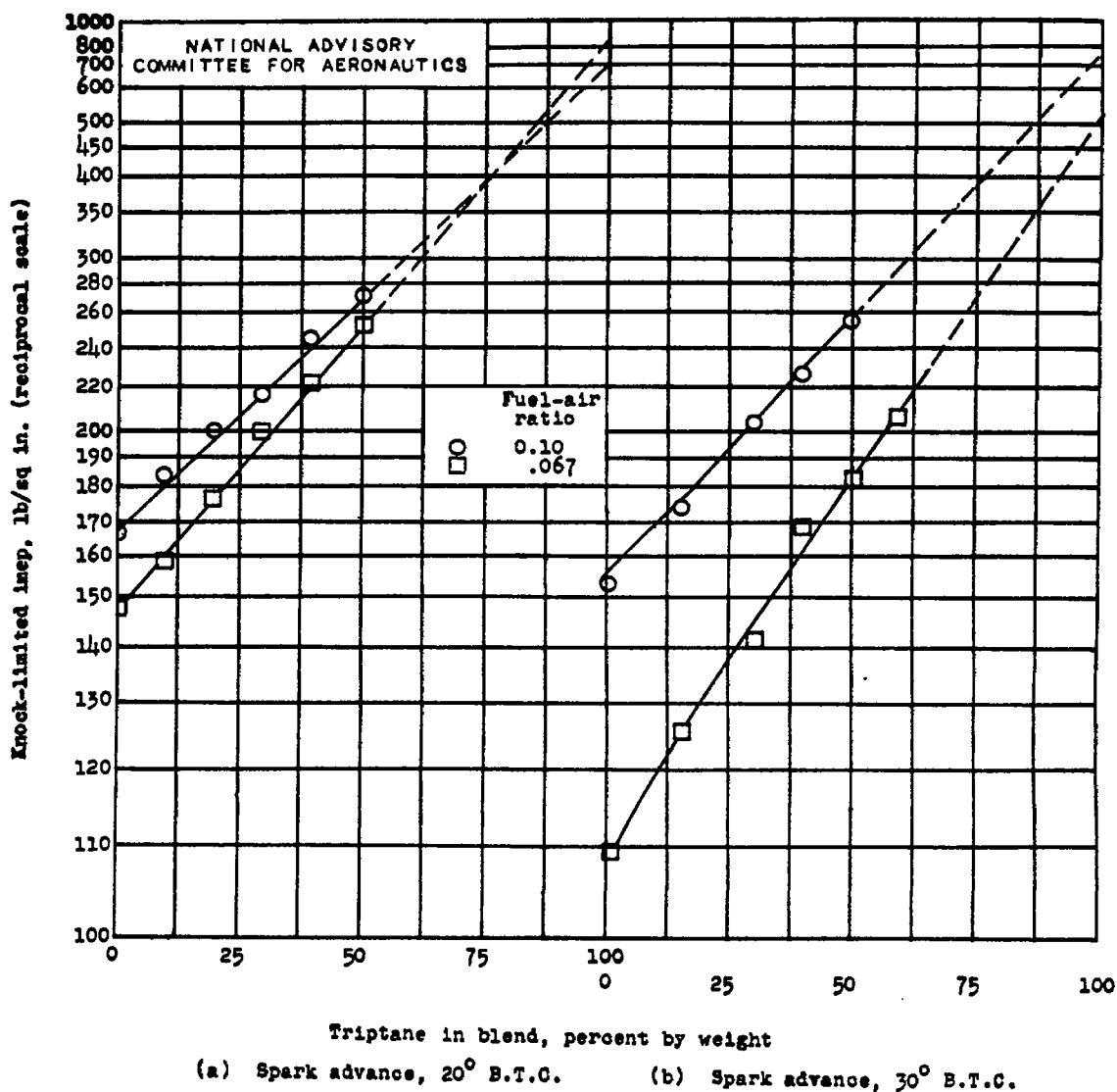


Figure 5. - Relation of knock limit to composition of blends of triptane with virgin base containing 4 ml TEL per gallon. Full-scale air-cooled cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.

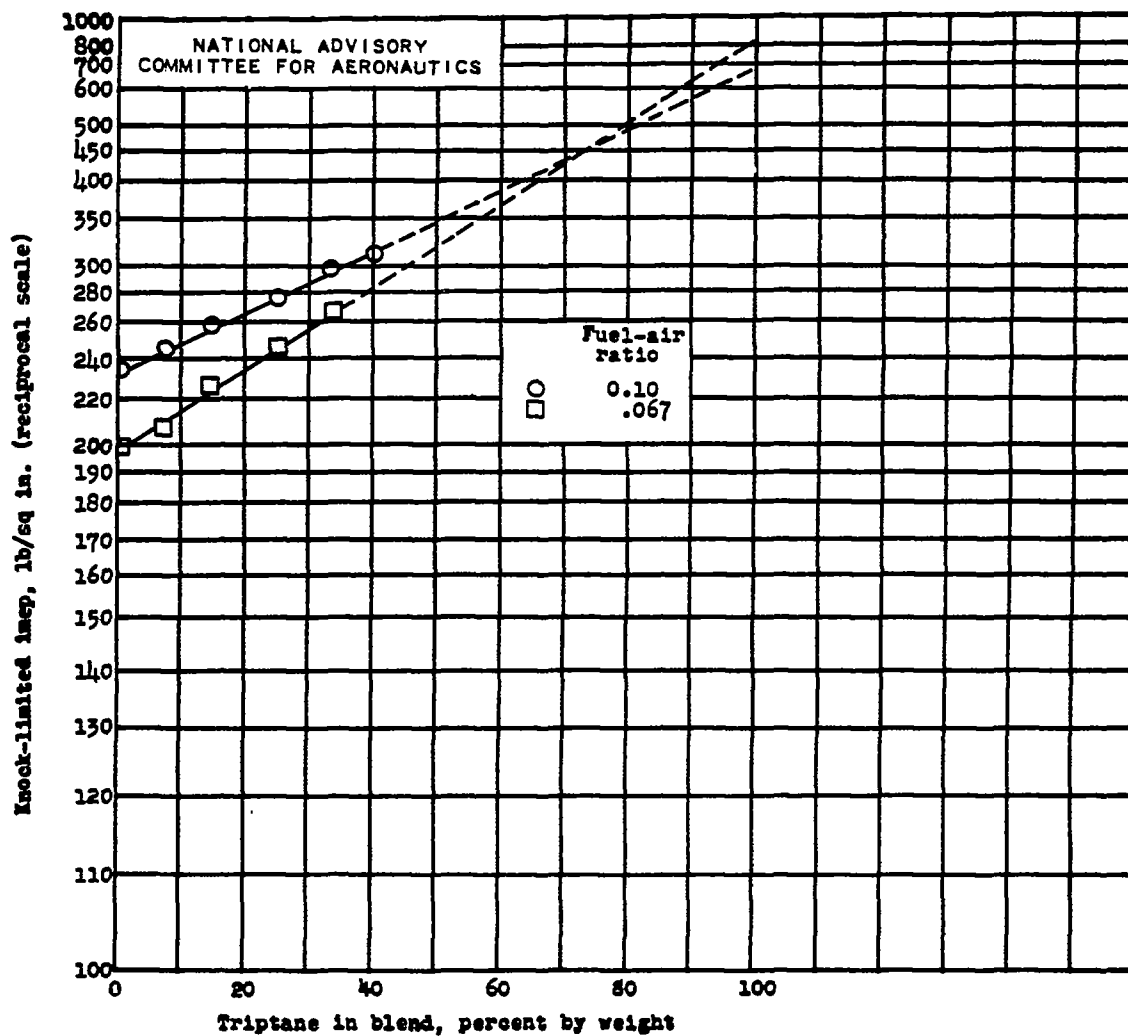


Figure 6. - Relation of knock limit to composition of blends of triptane with alkylate containing 4 ml TEL per gallon. Full-scale air-cooled cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F; spark advance, 20° B.T.C.

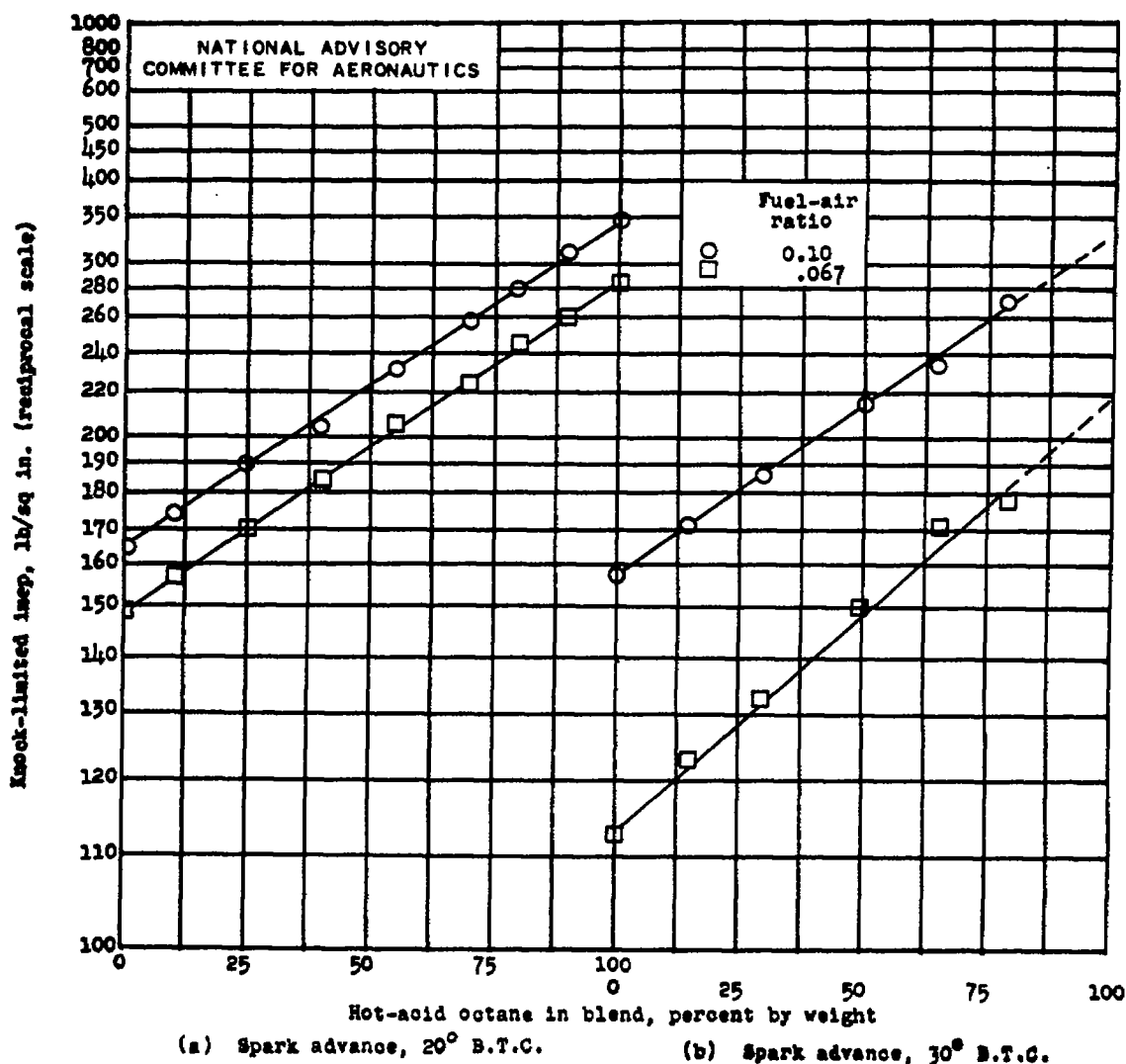


Figure 7. - Relation of knock limit to composition of blends of hot-acid octane with virgin base containing 4 ml TEL per gallon. Full-scale air-cooled cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.

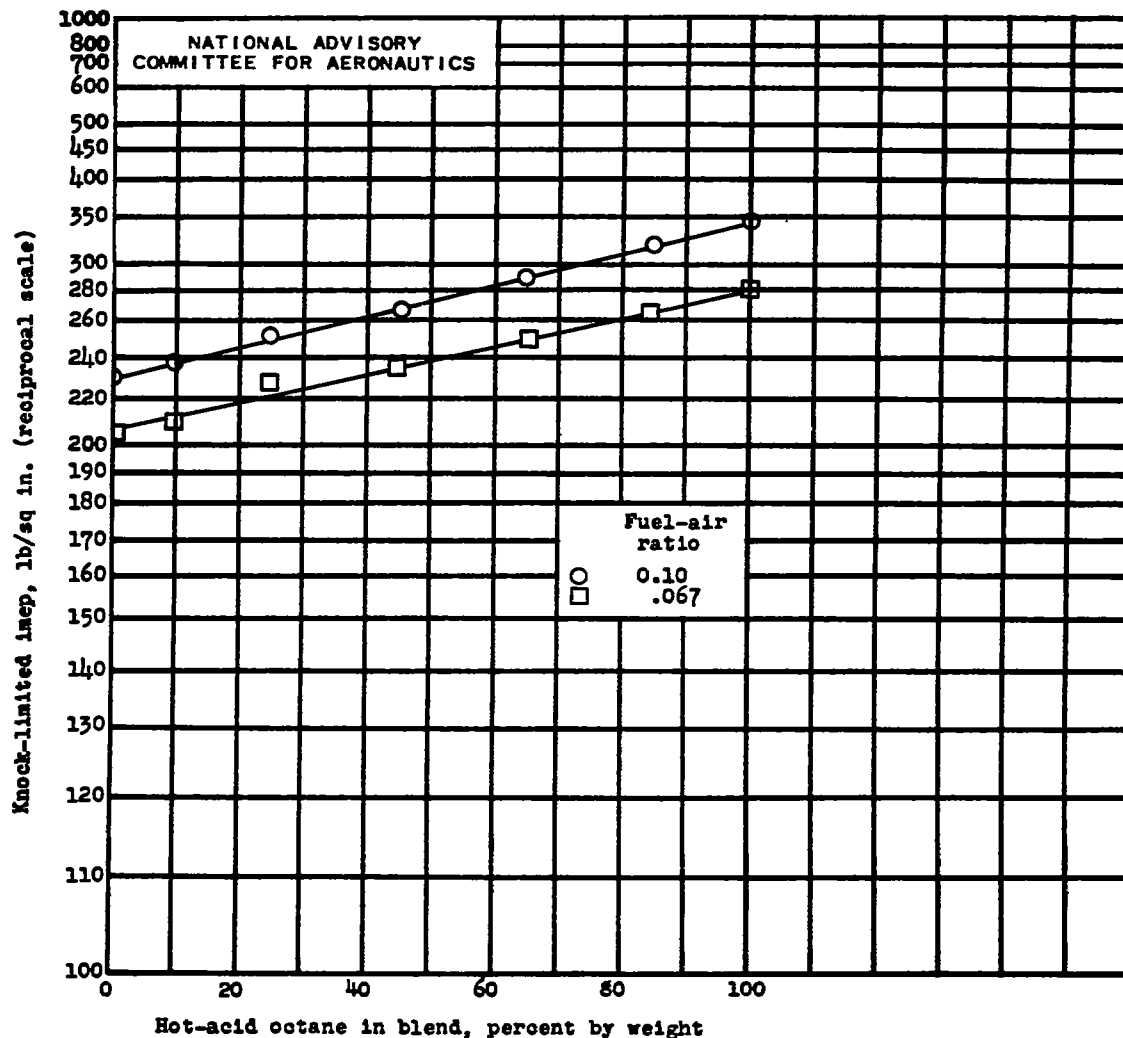
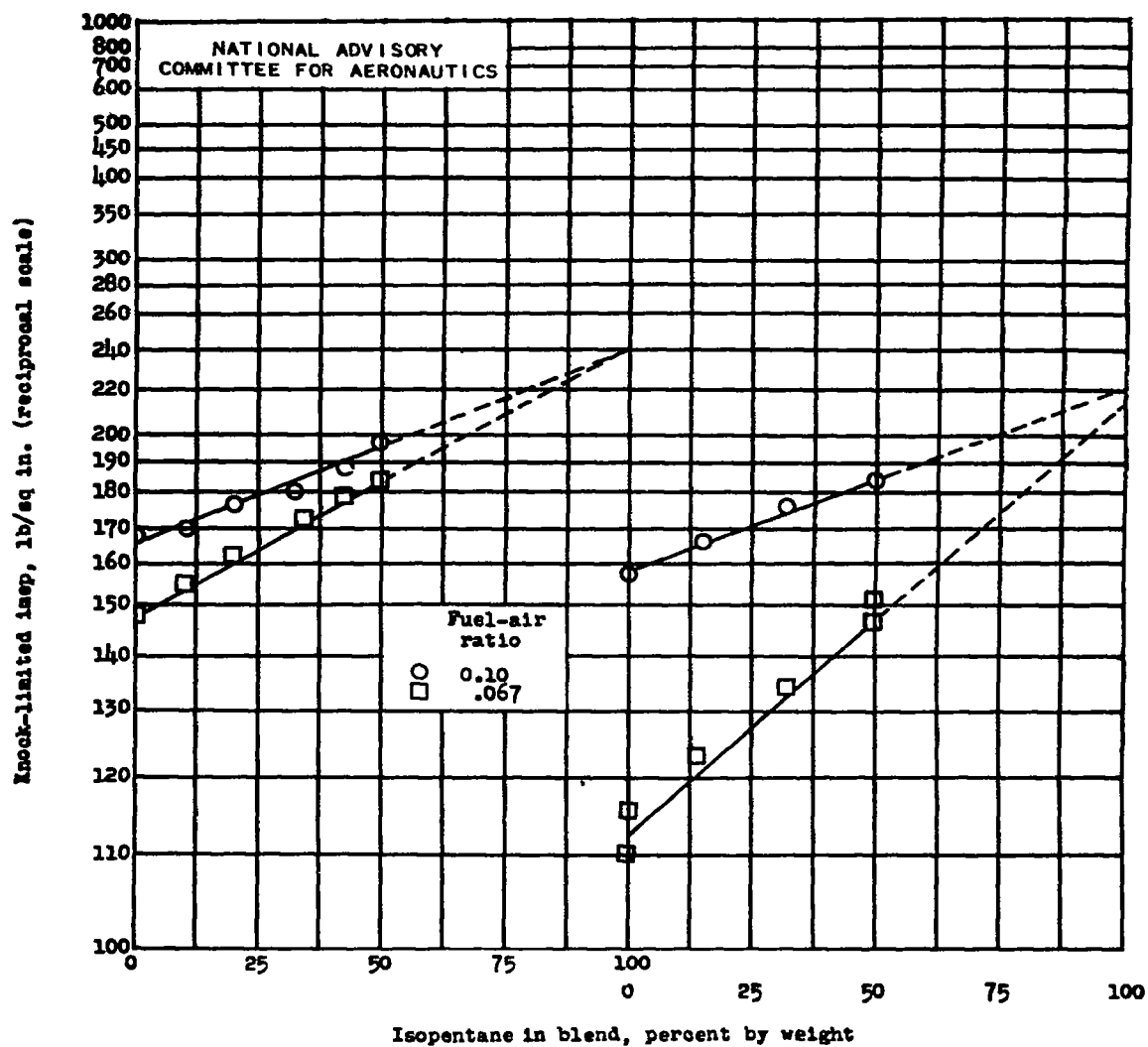


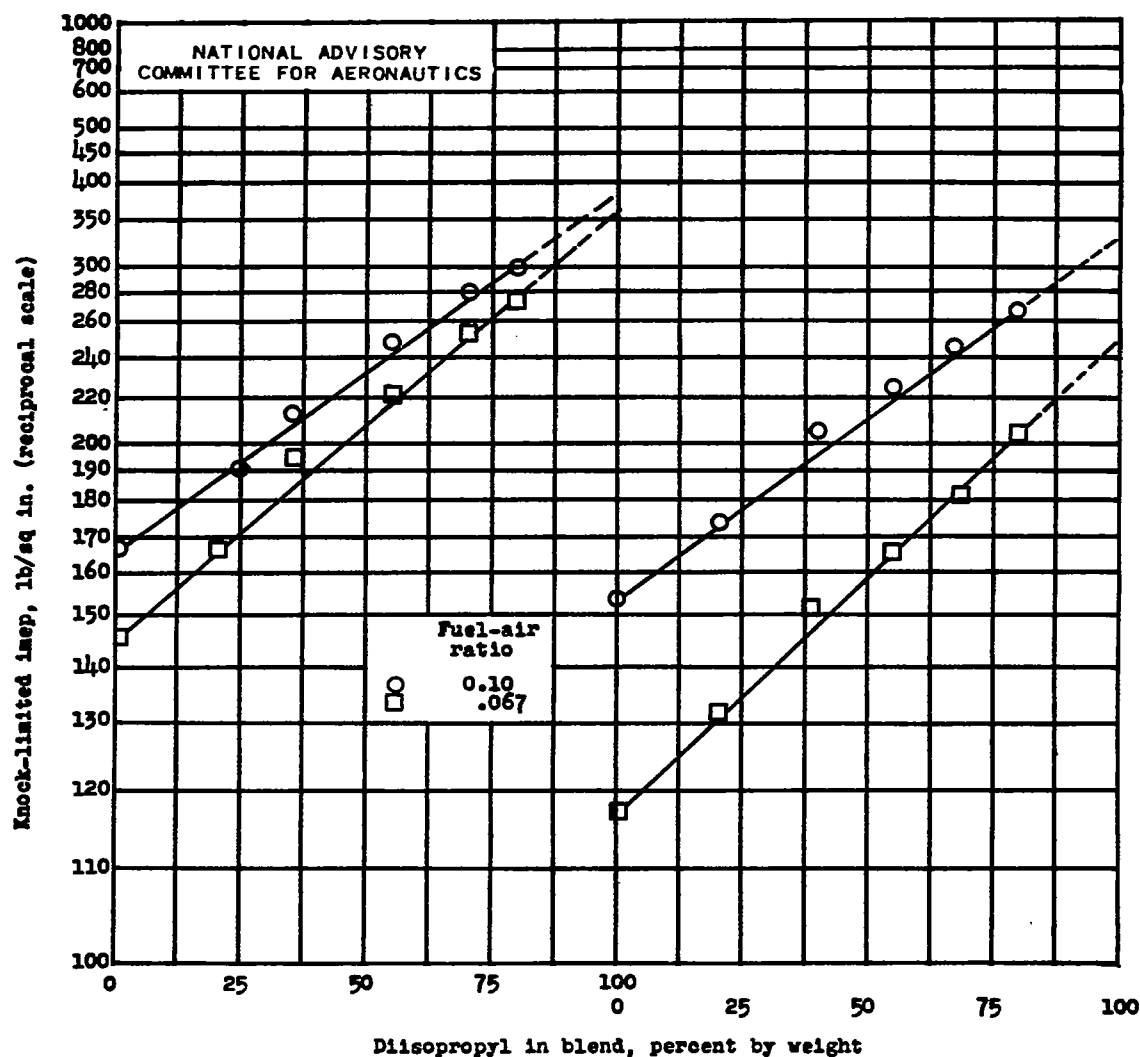
Figure 8. - Relation of knock limit to composition of blends of hot-acid octane with alkylate containing 4 ml TEL per gallon. Full-scale air-cooled cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F; spark advance, 20° B.T.O.



(a) Spark advance, 20° B.T.C.

(b) Spark advance, 30° B.T.C.

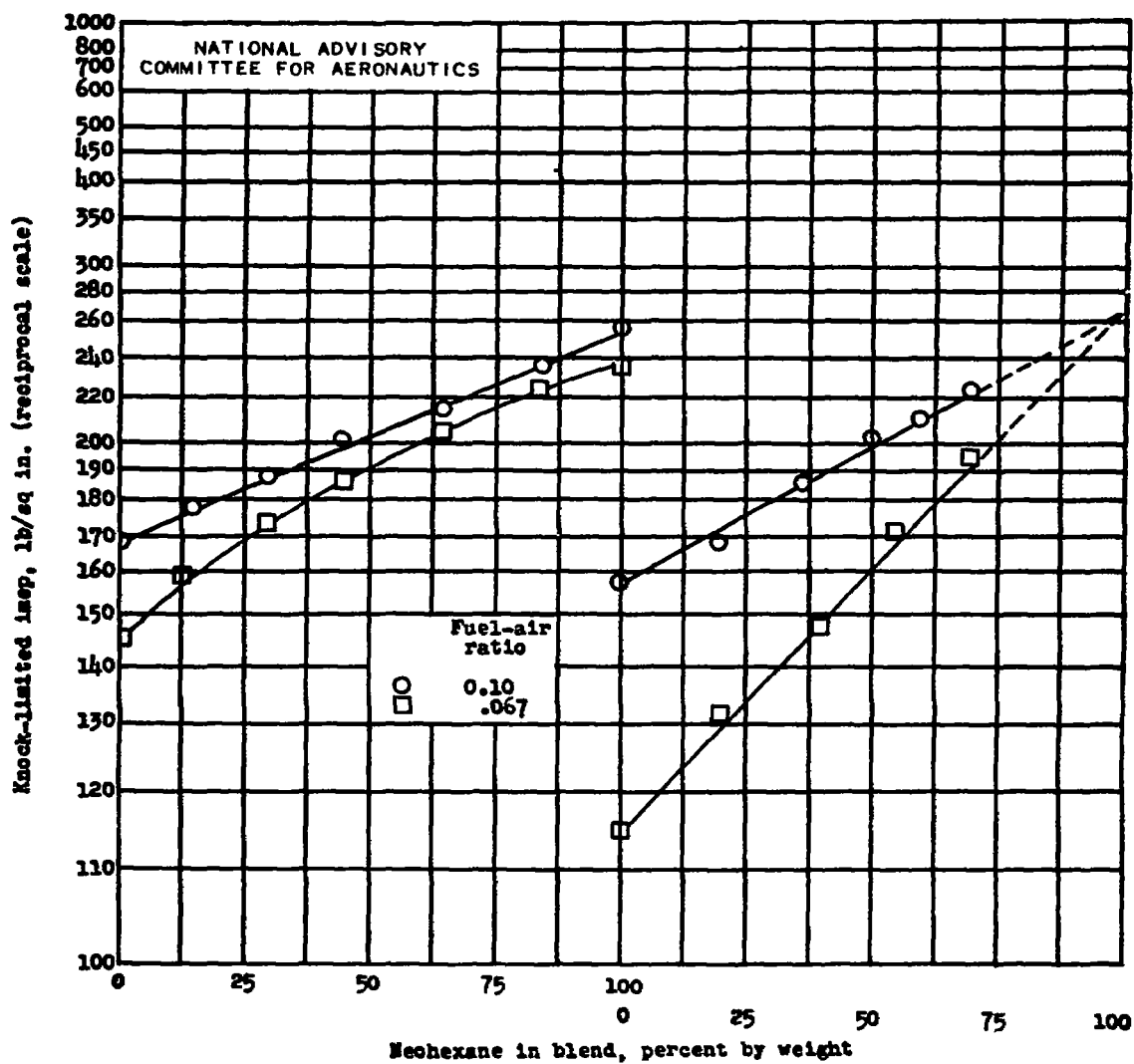
Figure 9. - Relation of knock limit to composition of blends of isopentane with virgin base containing 4 ml TEL per gallon. Full-scale air-cooled cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.



(a) Spark advance, 20° B.T.C.

(b) Spark advance, 30° B.T.C.

Figure 10. - Relation of knock limit to composition of blends of diisopropyl with virgin base containing 4 ml TEL per gallon. Full-scale air-cooled cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.



(a) Spark advance, 20° B.T.C.

(b) Spark advance, 30° B.T.C.

Figure 11. - Relation of knock limit to composition of blends of neohexane with virgin base containing 4 ml TEL per gallon. Full-scale air-cooled cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.

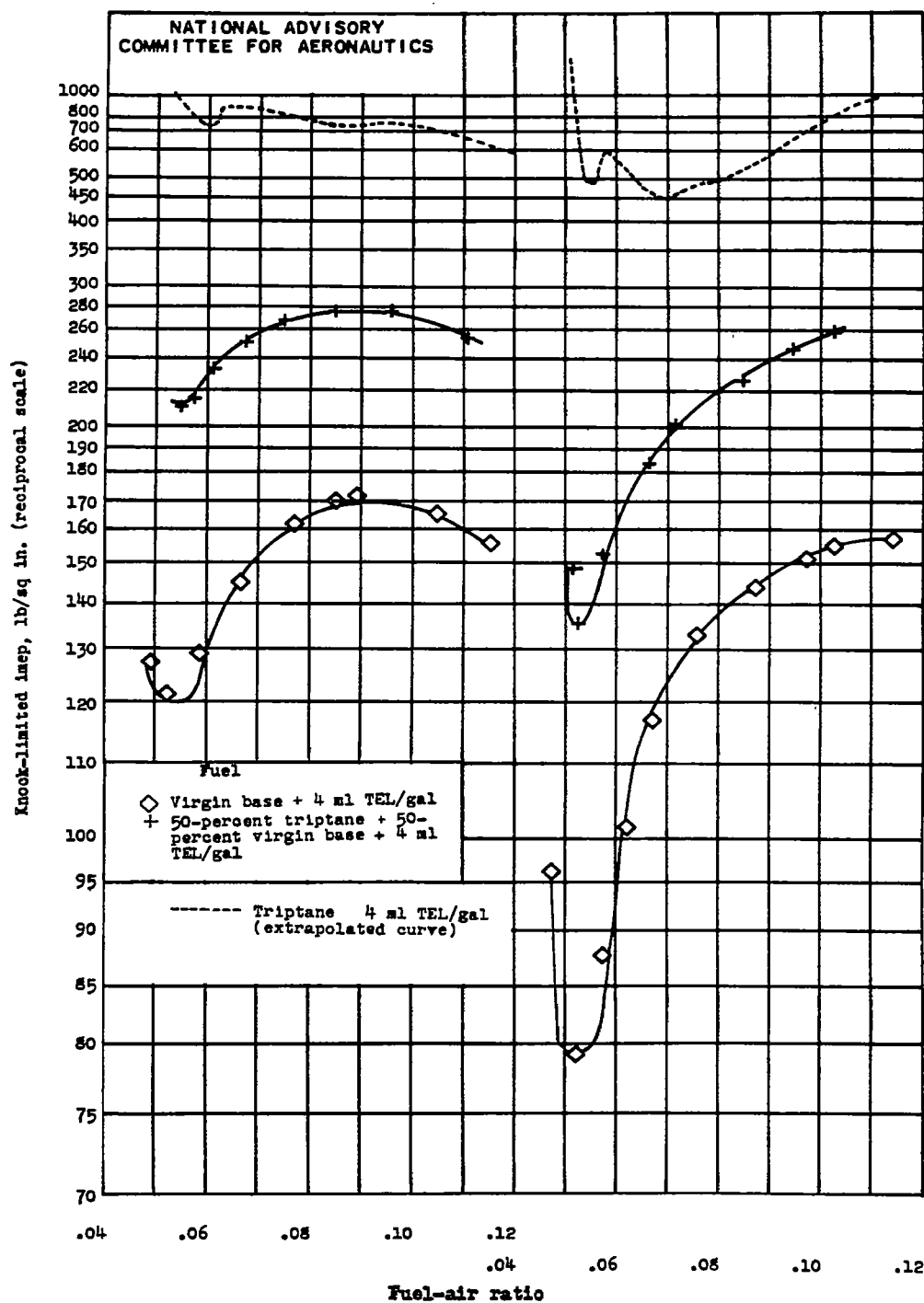
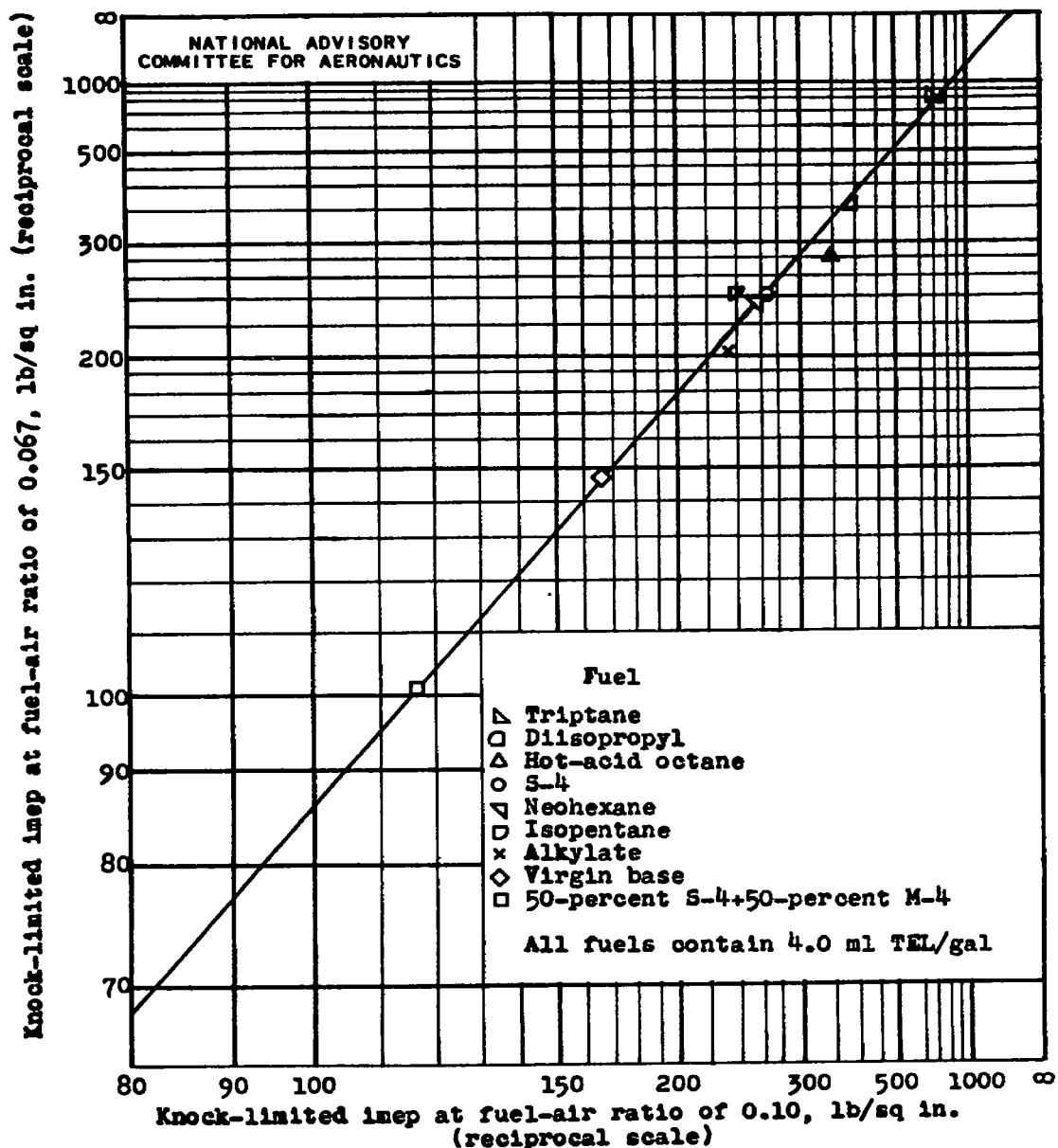
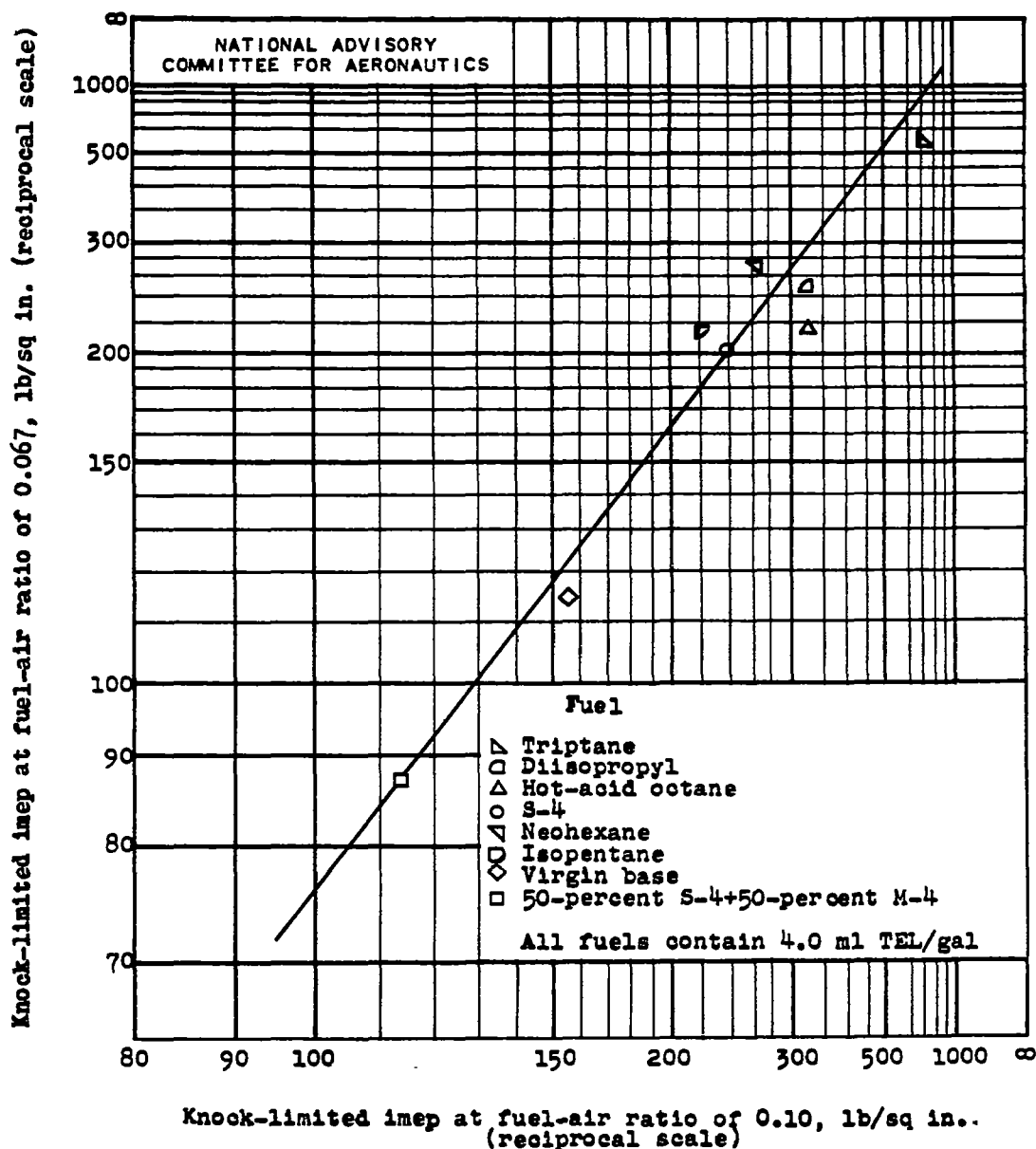


Figure 12. - Extrapolated knock-limited mixture-response curve for triptane plus 4 ml TEL per gallon. Full-scale air-cooled cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.



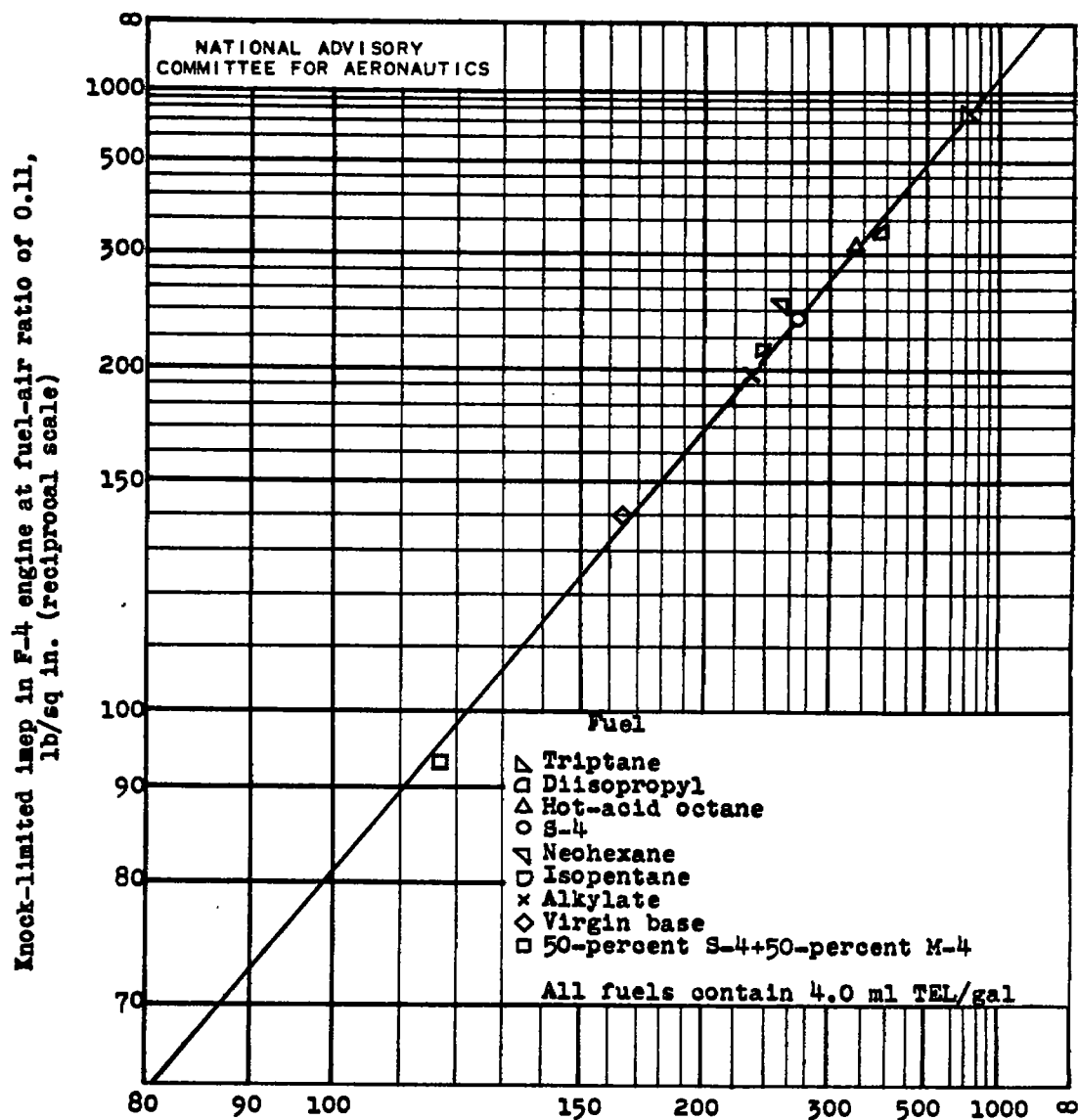
(a) Indicated mean effective pressures at spark advance of 20° B.T.C.

Figure 13. - Correlation between knock limits at rich and lean mixtures. Full-scale air-cooled cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.



(b) Indicated mean effective pressures at spark advance of 30° B.T.C.

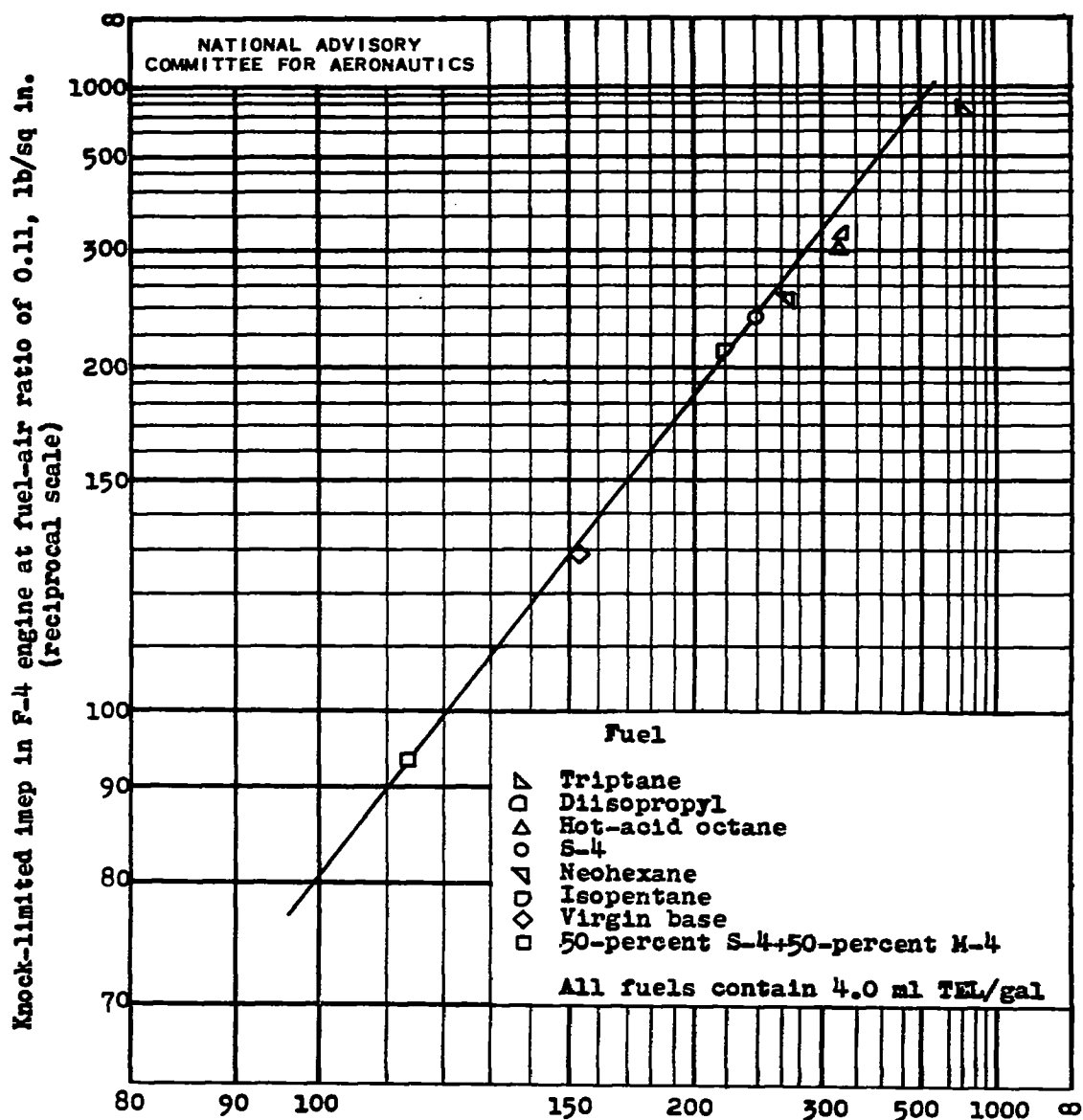
Figure 13. - Concluded. Correlation between knock limits at rich and lean mixtures. Full-scale air-cooled cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.



Knock-limited imep in full-scale air-cooled cylinder at
fuel-air ratio of 0.10, lb/sq in. (reciprocal scale)

(a) Indicated mean effective pressures at spark advance of 20° B.T.C.

Figure 14. - Correlation between knock-limited data obtained at F-4 conditions and in full-scale air-cooled cylinder at the following conditions: Compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.



Knock-limited imep in full-scale air-cooled cylinder at
fuel-air ratio of 0.10, lb/sq in. (reciprocal scale)

(b) Indicated mean effective pressures at spark advance of 30° B.T.C.

Figure 14. - Concluded. Correlation between knock-limited data obtained at F-4 conditions and in full-scale air-cooled cylinder at the following conditions: Compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.

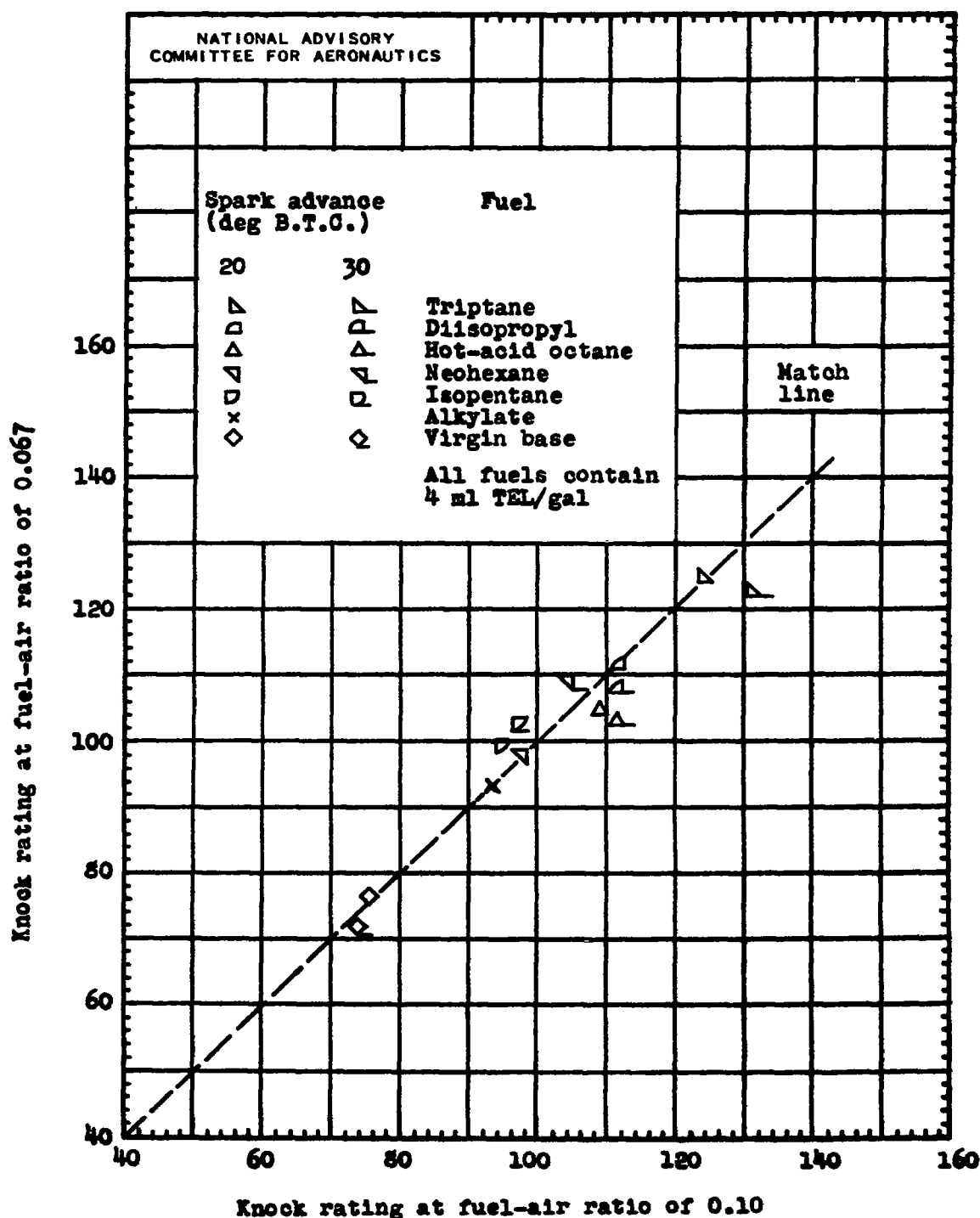


Figure 15. - Correlation of knock-limited ratings at rich and lean mixtures expressed as percentage of S-4 plus 4 ml TEL per gallon with M-4 plus 4 ml TEL per gallon. Full-scale air-cooled cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.

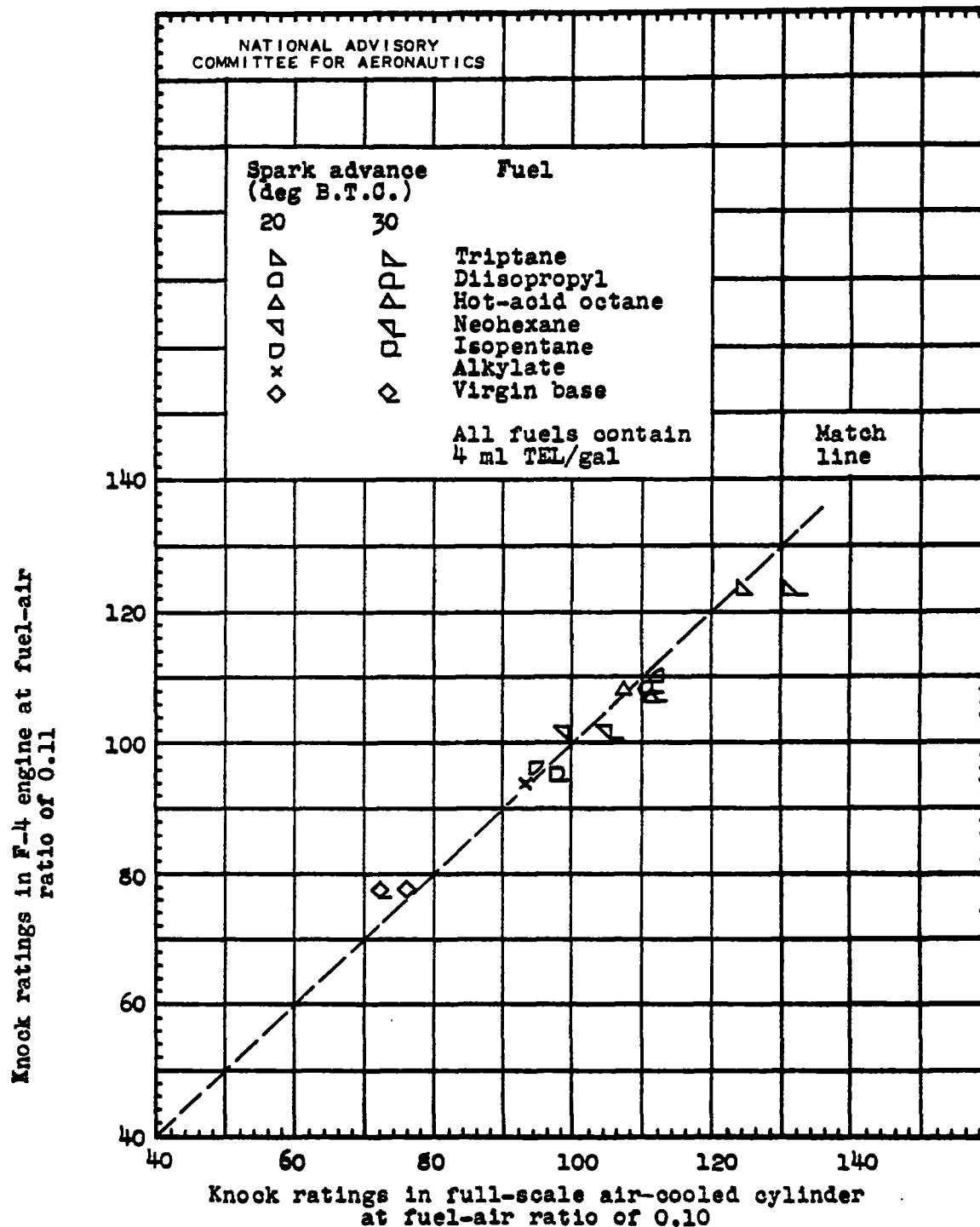


Figure 16. - Correlation of knock-limited ratings expressed as percentage S-4 plus 4 ml TEL per gallon with M-4 plus 4 ml TEL per gallon. Data obtained at F-4 conditions and in full-scale air-cooled cylinder at following conditions: Compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.

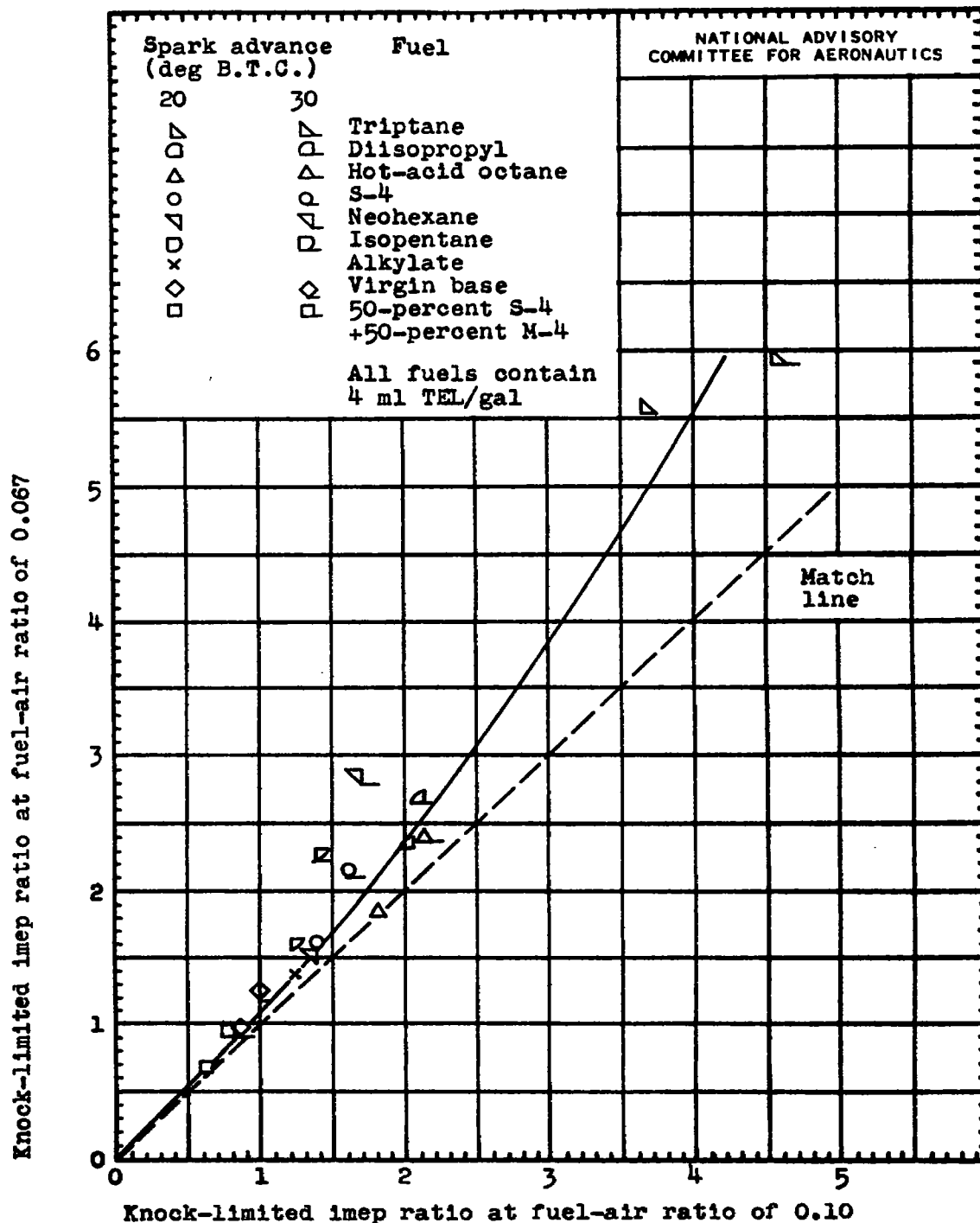


Figure 17. - Correlation of knock-limited ratings expressed as ratios of knock-limited indicated mean effective pressure of test fuel relative to clear S-4 reference fuel. Full-scale air-cooled cylinder; compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F.

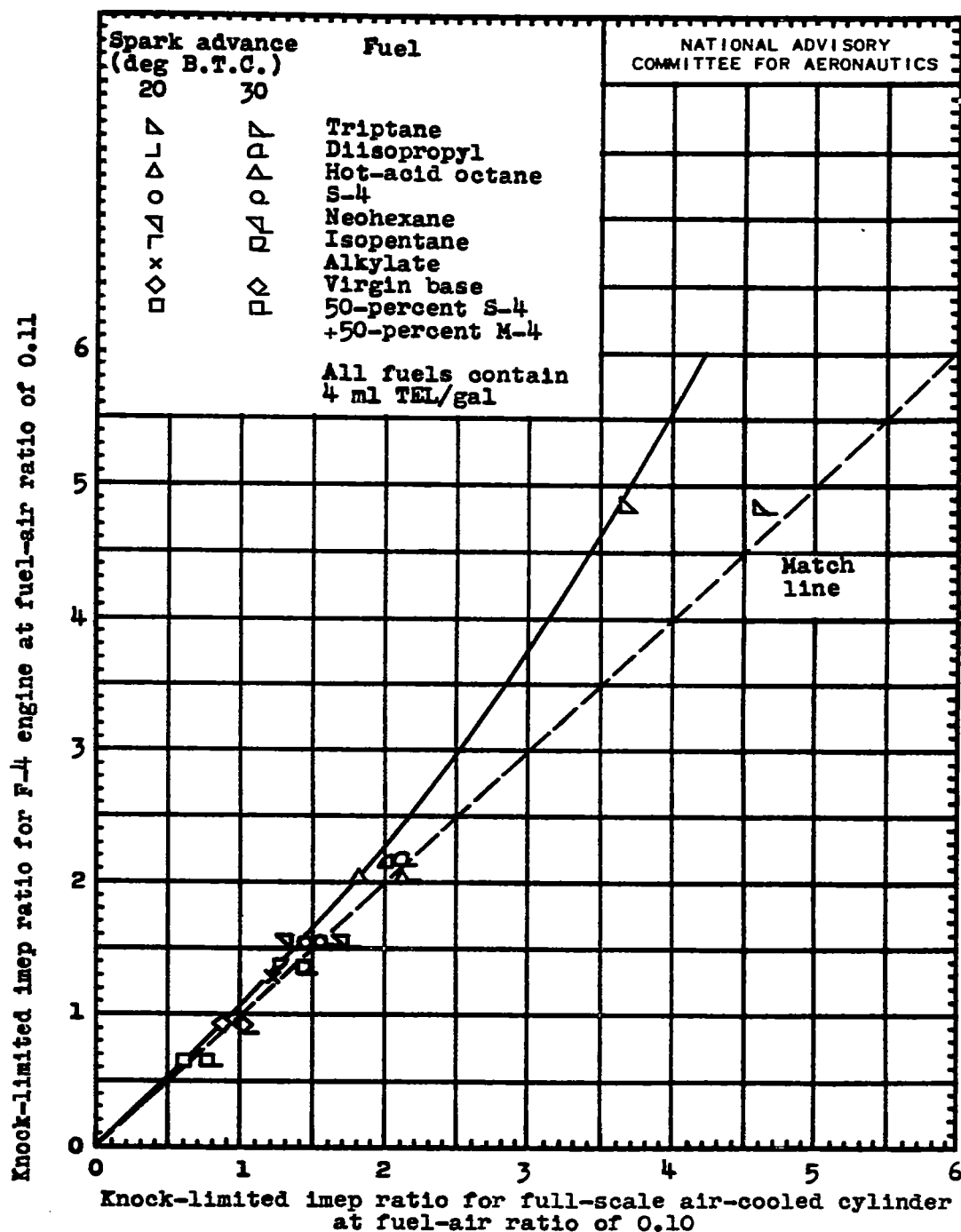


Figure 18. - Correlation of knock-limited ratings expressed as ratios of knock-limited indicated mean effective pressure of test fuel relative to clear S-4 reference fuel. Data obtained at F-4 conditions and in full-scale air-cooled cylinder at following conditions: Compression ratio, 7.7; engine speed, 2000 rpm; inlet mixture temperature, 2400 F; cylinder-head temperature at exhaust end zone, 3500 F.